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by

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PREPROCESSING IN CODE TRACKING ERROR DETECTOR AND PSEUDO-DISTANCE MEASUREMENT OF GPS

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Abstract: The article discusses the design method of time delay locking ring of a code tracking error detector with extended range. A fundamental algorithm is given that can efficiently solve the self adaptive code tracking error in an estimator, and the tracking error of the correlated code.

Key words: global positioning system (GPS), code tracking ring, inertial navigation system (INS).

INTRODUCTION

The performance indicators of GPS and any other hybrid systems related to GPS rely highly on the synchronism capability that can continuously maintain in the GPS receivers, and the local C/A code. Because of this reason, the code tracking error detector of extended range and the advanced hybrid technique of

GPS/INS are used in various highly mobile carriers in a jamming environment. In the intermediate jamming environment (GPS STATE 6) or in a state of very little or no jamming (STATE 5), the code ring is supplemented by the velocity provided by the carrier wave ring. In a setting of high jamming and high mobility (GPS STATE 3), the carrier wave ring can easily be unlocked, thus the navigation guidance information should be used to supplement the code ring. The two following problems should be considered when using low precision INS to supplement the code ring:

(1) effectiveness of supplementation: by applying the code ring of a standard error detector, the tolerance limit of the tracking error is plus or minus one code frame. This needs precision requirements in the supplementation with INS. (2) The stability of the entire GPS/INS system: for a code ring operating in a narrow band, the code tracking error is correlated.

An early translation signal and a delayed translation signal of the local code are used in a standard time delay locked detector; both signals are subjected to correlation processing with the input signals, in order to generate the code ring driving signal. Correlation computation is performed on the input signals and the different translation signals of the local code with the time delay locked detector of extended range, thus forming the code ring driving signal. Therefore, the tolerance limit of the tracking error can be relaxed with respect to the code ring. This article discusses the design method for the time

delay locked ring for the code tracking error detector with extended range. A fundamental algorithm is given that can efficiently solve the correlated code tracking error for the estimator of the self adaptive code tracking error.

I. Description and Design of an Extended Range Detector

The GPS receiver employs a noncorrelated time delay locking ring (DDL) to continuously maintain synchronization of the received code and the local C/A.

The input circuit of the ring channel is:

$$S(t) = (2S)^{1/2} S_{CA}(t - \tau_d) m(t - \tau_d) \cos[\omega_o t + 0(t)] \tag{1}$$

The noise is: $$n(t) = (2)^{1/2}\{Nc(t)\cos[\omega_o t + 0(t)] - Ns(t)\sin[\omega_o t + 0(t)]\} \tag{2}$$

In the equations, S represents the signal average power; $S_{CA}(t-\tau_d)$ is the received CA code; τ_d is the propagation time delay; $m(t-\tau_d)$ is the navigation data; ω_o is the carrier frequency; $0(t) = 0_o(t) + \Omega_o(t)$ is the unknown carrier wave phase. $Nc(t)$ and $Ns(t)$ are interdependent. For steady low throughput gaussian white noise, the single sideband spectral density is No W/Hz; and single sideband width is $B_H \leqslant \omega_o / 2\pi$.

Let $\tau_e = \tau_d - \hat{\tau}_d$, $\hat{\tau}_d$; is the estimation value of the time delay locked ring with respect to τ_d ; τ_e is the time delay error. indicates the width of the code frame of C/A code. Then the

fundamental execution equation of the time delay locked ring is:

$$\dot{\tau}_e/\Delta = \dot{\tau}_d/\Delta - KF(p)[Sm^2(t-\tau_d)g(\tau_e/\Delta) + n_e(t,\tau_e/\Delta)] \quad (3)$$

In the equation: K is the gain of the ring channel; F(p) indicates the transfer function $m^2(t) = H_L(p)m(t)$ of the ring channel filter. H_L indicates the equivalent low throughput property of the transfer function H(s) of the bandpass filter; $g\ (\tau_e/\Delta)$ is the tracking error detector; $n_e(t,\tau_e/\Delta)$ is the equivalent additive property noise introduced by the ring channel; the linear region of $g(\tau_e/\Delta)$ is $|\tau_e/\Delta| \leqslant 1/2$. In this range, the ring channel can track τ_d . When $|\tau_e/\Delta| \geqslant 1/2$, the correlated detector is unable to form an effective driving signal to track τ_d . Therefore, another operating mode, capture, of the ring channel requires an additional logic circuit, such as search control, to execute the capture. We can see, from Eq. (3), that when there is no input noise the linear zone of the detector is expanded; the properties of the ring channel are superior to those of a standard ring. When there is input noise, with an increase in the detector linear zone, the tolerance limit of the tracking error with regard to the ring channel can be increased. In addition, the introduced noise of the ring channel is increased.

With respect to the unitary self correlated function of C/A code, the following equation can be used for its expression:

$$R(\tau) = \begin{cases} 1-|\tau| & |\tau| \leqslant 1 \text{ code frame} \\ 0 & \text{the others} \end{cases} \quad (4)$$

With respect to the design concept of the extended range detector, the translation of code ring generates several advanced local code, 1, 2, 3, ... code frames, and delayed 1, 2, 3, ..., signal code frame. These signals are related to the input signals. For weighted summation of related quantities, as the driving signal of the code ring the form of the extended range detector can be expressed as the following equations:

$$f(e) = \sum_{i=-\infty}^{\infty} W_i R_i(e+i) \tag{5}$$

By using Eq. (5) to replace $g(\tau_e/\triangle)$ in Eq. (3), we obtain the working equation of the new locked ring. The noise increased by Eq. (5) is limited to an acceptable level to optimize the weighted coefficient W_i. By using the Fokker-Planck method to solve the nonlinear differential equation ($g(\tau_e/\triangle) = f(\tau_e/\triangle)$) of Eq. (3), we obtain the steady state probability spectral density Pf(e) of the unitary time delay error $\tau_e/\triangle = e$. Then by determining that the mean square error of e is at a minimum for the index function of W_i , then we have:

$$\lim_{t\to\infty} E\{\sigma_e^2(f)\} = \int_{-\infty}^{+\infty} e^2 Pf(e)\mathrm{d}e \tag{6}$$

The constraint conditions are:

$$\int_{-\infty}^{+\infty} Pf(e)\mathrm{d}e = 1 \tag{7}$$

$$\int_{-\infty}^{+\infty} f^2(e)\mathrm{d}e < \infty \tag{8}$$

By satisfying Eq. (7), this indicates that Pf(e) is the effective probability density. By satisfying Eq. (8), this indicates that the noise introduced is a limited variable. Thus, W_i can be determined by using a standard variation algorithm. Finally, the extended range detector thus obtained is linear segment by segment, as shown in Fig. 1.

In the advanced GPS/INS hybrid system, we obtain the code tracking error detector with self-adaptive extended range. From INS data, we can directly determine the time varying parameter in

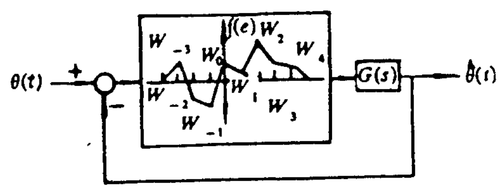

Fig. 1. Model of fundamental passband of noncorrelated code ring by adopting an extended range detector

the effective pseudo-distance mobile model. From GPS data and INS data, we can determine the signal to noise ratio of the received signal. The code tracking error detector with self adaptive extended range is a parallel correlated treatment process. Based on the mobile state of the estimated GPS signal and the ECM power, the bandwidth of the tracking ring and the weighted coefficient W_i of the multichannel correlator can be optimally adjusted to obtain the optimal tracking performance.

II. Description and Design of Code Tracking Error Estimator

To upgrade the antijamming capability of a GPS receiver and to filter out additional noise introduced by the code tracking error detector with extended range, the DLL should be in the narrow band operating status. The time constant is very large, considerably greater than the measurement cycle of the GPS/INS integrated Kalman filter (IKF). Therefore, the code tracking error in the pseudo-distance measurement of the IKF is not only related to time, but also is related to the INS error in mode setting of the IKF. To satisfy the statistical requirements of IKF in measuring noise, without causing instability and performance degradation of the entire GPS/INS system, the pseudo distance measurement should be preprocessed. In other words, the correlated processing should be solved with respect to the correlated code tracking error. Thus, the designed tracking error estimator of self-adaptive code can accomplish this task. Here, by using the first-order narrow band code ring supplemented with the inertial velocity since it is the narrow band code ring, the tracking error induced by the INS supplementary error will be very slowly filtered out. From the output of the correlated error detector, sampling is done with the ring channel (the sampling frequency is 1/Ts). The resulting measurement, including the code tracking error is:

$$Z = h\delta\rho_{TRK} + V \tag{9}$$

In the equation, $\delta\rho_{TRK}$ is the code tracking error; h is a coefficient related to such factors as the correlated error detection network gain and the self correlated function of C/A code. V is the measured noise.

If the measurement cycle of IKF is Tm, the sampling cycle of the code tracking ring is Ts. Then, in Tm the measurement number of Eq. (9) is K=Tm/Ts. In the following, the Kalman filtering technique is applied to design the code tracking error estimator. The selected status variable is the code tracking error and its variability, that is, $X = [\delta\rho_{TRK},\ \delta\dot{\rho}_{TRK}]^T = [X_1, X_2]^T$. The system status equation is:

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -1/Tc \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 0 \\ W \end{bmatrix}$$

After being subjected to divergence:

$$X_{k+1} = \Phi_{k+1,k} X_K + W_k \tag{10}$$

The measurement equation is: $Z = HX_K + V_K$ (11)

In the equations $H = [h, 0]^T$, Tc is the correlated. W_K and V_K are the zero mean values. The mutually unrelated kinds of gaussian white noise are:

$$E[W_K W_L^T] = Q_K \delta_{KL} \qquad E[V_K V_L^T] = R_K \delta_{KL} \qquad E[W_K V_L^T] = 0$$

The code tracking error estimator is restricted by the IKF measurement cycle. As the number of measurements are limited and in order to avoid temporary correlation of IKF measurements, beginning at each IKF measurement interval, re-initiation of the code tracking error estimator should be performed. In the actual

application case, the key to successfully applying the Kalman filter is to know sufficient pre-inspection signals of the actual system. Q_K indicates the dynamic variation of the ring cycle; R_K indicates the input noise intensity. Since we are unable to precisely know Q_K and R_K in advance, therefore a kind of self adaptive Kalman filter is used to effectively estimate the code tracking error. The algorithm is as follows:

$$\hat{X}_k = \hat{X}_{k/k-1} + K_k \varepsilon_k \qquad \hat{X}_{k/k-1} = \Phi_{k,k-1} \hat{X}_{k-1} \qquad \varepsilon_k = Z_k - H_k \hat{X}_{k/k-1}$$

$$P_{k,k-1} = K_{k-1}(\varepsilon_k \varepsilon_k^T) K_{k-1}^T + P_{k-1}$$

$$\hat{R}_k = (1 - d_{k-1})\hat{R}_{k-1} + d_{k-1}[\varepsilon_k \varepsilon_k^T - H_k P_{k,k-1} H_k^T]$$

$$d_k = (1-b)/(1-b^{k+1})$$

$$K_k = P_{k,k-1} H_k^T [H_k P_{k,k-1} H_k^T + \hat{R}_k]^{-1}$$

$$P_k = [I - K_k H_k] P_{k,k-1} [I - K_k H_k]^T + K_k \hat{R}_k K_k^T$$

In the equations, b is the forgotten factor, 0<b<1.

To check the effectiveness of this algorithm, computer simulation was conducted. With respect to the system, we assume the following: $Tc = 60\text{s}$, $Q = 5$, $R = 0.45$, $h = 1$, $\mathrm{E}[X_0] = [0,0]^T$, $P_0 = \mathrm{Diag}[625,25]$. With respect to the filter, we assume the following: $Tc = 60\text{s}, R = 1$, $h = 1$, $X_0 = [0,0]^T$, $Tm = 1\text{s}$, $Ts = 0.02\text{s}$, $b = 0.95$. Fig. 2 shows the estimated value of the code tracking error. In the estimated value, $\delta\rho_{TRK}$ is the real status; $\delta\hat{\rho}_{TRK}$ is the estimated status. From the figure, we known that the estimated value of the code tracking error is satisfied.

The residue measurement difference of IKF is: $Z = \delta\rho_{EST} - \delta\rho_{TRK}$. In the equation: $\delta\rho_{EST}$ is the pseudo-distance estimated error of

INS. By using the code tracking error estimator, we can solve for the correlated noise in the correlated IKF measurements. In addition, the noncorrelated noise V_{ADD} is increased in IKF measurements. Therefore, by solving the correlated effectiveness two parameters can be used in the description. K indicates the signal gain, indicating the proportion of the error in the pseudo-distance estimated value in the residue difference in actual

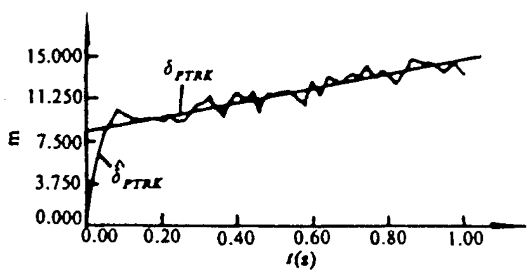

Fig. 2. Effect of code tracking error estimator

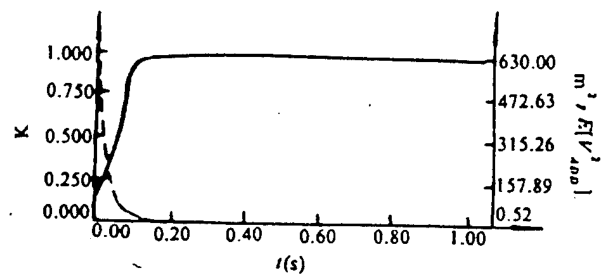

Fig. 3. Signal gain and additional noise

measurements, and the ideal value is 1. V_{ADD} is the additional measured noise.

$$\overline{\delta\rho}_{TRK} = \delta\rho_{TRK} - \delta\hat{\rho}_{TRK}$$

$$K = E[\delta\rho^2_{EST}] / \{E[\delta\rho^2_{EST}] + E[\overline{\delta\rho}^2_{TRK}]\}$$

$$E[V^2_{ADD}] = E[\overline{\delta\rho}^2_{TRK}]\}$$

If there is no code tracking error compensator, K=0.2, $E[\delta\rho^2_{EST}] = 100$. After using the code tracking estimator and by assuming that the cycle of IKF filtering is 1s (the sampling interval in the ring channel is Ts=0.02s). Fig. 3 shows the simulation results. Finally, K can reach 0.9 and $E[V^2_{ADD}]$ can be

reduced to 0.5. Therefore, the designed code tracking error estimator with self-adaptive feature can be effective to solve the correlated noise in the correlated IKF measurements, to provide ideal measurements for IKF.

III. Conclusions

The article discusses the method of designing a time delay locked ring by adopting the extended range detector. Moreover, a concept is proposed to design a self-adaptive detector in the GPS/INS advanced hybrid system. By adopting the time delay locked ring, for the expanded range detector, the tolerance limit of the code tracking error will be greatly increased, thus upgrading its antijamming property, and high capability in mobile status, and reduced precision requirements with INS supplementation. Moreover, the locked ring can be captured and the two operating statuses for tracking can be accomplished with a single tracking treatment. The designed code tracking error estimator with self-adaptive feature can effectively convert the correlated noise into white noise, thus the pseudo-distance measurements can be better matched with IKF in order to obtain a reliable and robust GPS/INS system.

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